Environmental Toxicology and Microbiology Vol 1

Author: Alphaxad Daudi

Date:2025

Fecal And Heavy Metal Contamination

HUMAN HEALTH RISK ASSESSMENT OF FECAL AND HEAVY METAL CONTAMINATION IN COASTAL WATERS. A CASE STUDY OF MSASANI BEACH, DAR ES SALAAM

Abstract-Fecal contamination can be caused by untreated sewage and defecation that introduces pathogens such as bacteria and viruses into coastal water. Industrial effluents, urban runoff and agriculture runoff introduces heavy metals such as lead, cadmium, arsenic and mercury into coastal water. Untreated sewage and defecation in coastal water have high pathogen load as they harbor microorganisms. These pathogens may lead to water related disease such as water borne diseases including typhoid fever, diarrhea and cholera. On other hand, heavy metal contamination in coastal water may lead to non-carcinogenic effects such as neurological damage, kidney damage and reproductive issues and cancer.

This study assessed human health implications associated with fecal and heavy metal contamination in coastal water at Msasani beach, Dar es salaam, aiming at identifying sources and level of coastal water pollution level, establishing human health risk assessment associated with fecal and heavy metal contamination and establishing mitigation measures to reduce identified human health risks for fecal and heavy metal contamination in coastal water. Data collection was done through document reviews, questionnaire, physical observation, interview and laboratory analysis of water samples at Msasani. It also used beta Poisson model for quantitative microbial risk assessment and other human health risk assessment methods from US EPA. FC/FS ratio was 3.27 implied human source as predominantly source of fecal contamination. All microbial risks of illness identified from each pathogen with their respective concentrations were above 0.0001 US EPA acceptable risk except for enterococcus with lower concentration. All hazard quotients for all metals were above 1 (high) except for Cd with minimum concentration in adult through dermal contact and all carcinogenic risks were not acceptable except for Pb. Finally, enforcement of sewage discharge and introduction of public toilet with proper sanitation facilities and strict punishment to households who open their toilets during rainfall seasons can reduce identified risks. Phytoremediation and constructed wetland can reduce heavy metal identified human health risks at this beach.

INTRODUCTION

Mostly, untreated sewage and defecation introduces pathogens such as bacteria and viruses into coastal water (Barcelo, 2020). Industrial effluents, urban runoff and agriculture runoff introduces heavy metals such as lead, cadmium, arsenic and mercury into coastal water (Boukich et al., 2024). Untreated sewage and defecation in coastal water have high pathogen load as they harbor microorganisms. Coastal water may be used to conduct different human activities such as swimming, so these pathogens may lead to water related disease such as water borne diseases including typhoid fever, diarrhea and cholera. On other hand, heavy metal contamination in coastal water may lead to non-carcinogenic effects such as neurological damage, kidney damage and reproductive issues and cancer affecting the exposed population (Genco, 2020).

In Mimika, Indonesia different studies that have been conducted had shown that sources of pollution in coastal water are from anthropogenic activities such as agricultural activities, fisheries, industrial effluents, fuel consumption, runoff from city garages, runoff from shops selling paint, domestic waste water, natural sources of metals from rocks and improper municipal waste water treatment practices. Polluted water have been found to have high microbial contamination, moderate heavy metal and persistent organ chemical from agricultural pesticides and fertilizers (Kemper, 2019).

In Omani, research studies conducted had shown that heavy metals found in ocean sediments, seafood such as fish and in water were in concentrations that may pose significant effects to human being. Mostly heavy metal that found in fishes were Cadmium, mercury and lead (Choudri et al., 2015). The common source of these heavy metal were found to be untreated sewage effluents (Barcelo, 2020).

In Tanzania, a lot of research papers that have been done to assess the quality of coastal water and pollution with different objectives to determine sources of pollution, level of microbial contamination and heavy metal (Machiwa, 2010). Research findings revealed that some coastal areas in Tanzania are not safe for contact recreation such as swimming and walking around those coastal lines. Example in ocean road sewer outfalls, coastal

areas at the discharge of Mzimbazi river. Coastal water that were found polluted had high level of microbial contamination (Mwakalobo et al., 2013). Indicators like fecal coliforms were found and in most areas for the case of heavy metals, lead and mercury were found mostly to exceed the WHO and FAO guidelines for contamination in coastal water and food (Mwakalobo et al., 2013). In Zanzibar some coastal areas were found to have high level of fecal contamination (Mohammed, 2002). This caused those contaminated zones to be restricted for swimming activities. Many research in Dar es salaam assessing coastal beaches water quality do not provide adequate information on the level of human health risk and their significance to cause potential harm to public health (Landrigan et al., 2020).

In Msasani beach, there is a presence of defecation and two municipal wastewater outlets that discharge wastewater directly into this coastal beach. Swimming activities are conducted at about 20 to 30 meters away from municipal wastewater outlets. It is known that accumulation of heavy metal through dermal contact to human can cause non carcinogenic effects and carcinogenic health effects. Also, fecal contamination can cause variety of water borne diseases such as typhoid fever, diarrhea and cholera.

In Tanzania, different studies have been conducted concerning fecal contamination but have been based on qualitative risks while there is limited information concerning quantitative microbial risk assessment in coastal water. Example is a work of (Hervio, 2016) and (Mushi, 2020), these studies determined concentrations of pathogens but they did not provide quantitative risks of each pathogen identified in contaminated coastal water. In this beach, people are allowed to swim without knowing the level of fecal and heavy metal contamination and quantitative microbial risks that may lead to clinical illness and death to exposed population (swimmers). Finally, the research will investigate on human health implications focus on coastal water pollution levels, quantitative microbial risk assessment and human health risk assessment associated with heavy metals such as Pb, Cd, Hg and Cr.

Main Objective

To assess human health implications associated with fecal and heavy metal contamination in coastal water at Msasani beach Dar es salaam.

Specific Objectives

I. To identify sources and level of coastal water pollution emphasis on fecal and heavy metals contamination
II. To establish human health risk assessment associated with fecal and heavy metal contamination
III. To establish mitigation measures to reduce identified human health risks for fecal and heavy metal contamination

Material and Methods

The study was conducted at Msasani beach, Dar es Salaam, Tanzania at a geographic location coordinates -6.760593,39.263368. Nearby areas are Mikocheni B, Msasani beach, Slipway and Namanga. Area has a population size of 14,640 people. The area was selected for this study because there is direct human exposure to swimmers due to presence of multiple pollution sources such as open defecation, sewage discharge and urban runoff. These sources have high potential to cause fecal and heavy metal contamination which might have significant public health risk.

Sampling technique

Sample selection

Sampling method used was systematic sampling, because it ensured even distribution and simple implementation of sample collection (Pandey, 2022). This sample collection points were depending on the point source of pollution, swimming zones and areas near defecation zones in the beach as shown in Table 3.1. Seven water samples were selected for microbial sampling analysis, they were named as A1, A2, A3, A4, A5, A6 and A7. Four water samples were selected for heavy metal analysis, they were named as A8, A9, A10 and A11.

Sampling procedures for microbial sampling according to US EPA guidelines

According to (Haugland, Oshima, & Varma, 2021), seven sampling points were selected, sampling glass bottles were sterilized in water bath at 100°C and used for sampling collection and sample bottles were labeled as A1, A2, A3, A4, A5, A6 and A7. On the surface of coastal water, bottle was submerged at 30 cm below the surface and away from the shore and were collected at different points selected before. Samples were transported and stored using ice bag and temperature of 2 to 8 °C were kept. Cool box was used to carry samples from site to laboratory.

Sampling procedures for heavy metals based on US EPA guidelines

According to (Remeteiova & Silvia, 2020), four water sampling point will be selected, polypropylene bottles of 1L were used, sample bottles were labeled as A8, A9, A10 and A11, bottles were soaked in nitric acid of 5% within 24 hours and rinsed with deionized water. Bottles were dried and sample of water were collected and pH were measured at the site during sample collection. Sample were acidified by 3mls of nitric acid to prevent adsorption of heavy metals to the bottle walls. Heavy metal analysis was done within 2 days from sample collection time at Sokoine University of Agricultural (SUA). Sample analysis method used was Atomic Absorption Spectroscopy (AAS) followed by documents and records.

Research design

The research design for this study was mixed research design. It combined elements of both quantitative and qualitative research. Methods used to collect qualitative data were in-depth interview, physical observation and document review and methods used to collect quantitative data were laboratory analysis and close ended questionnaire. Quantitative data obtained were such as colony counts for quantitative microbial risk assessment, concentrations of heavy metals, pH and Turbidity. All these data were numerical and identified as quantitative data. Later, qualitative data were used to interpret, description and give meanings of these obtained quantitative data and finally, they provided information on mitigation measures used to reduce identified human health risks for fecal and heavy metal contaminations.

Data Collection Methods

Questionnaire

Questionnaire was conducted for swimmers where the information obtained were health risk on exposure time and exposure frequency, water related diseases in relationship to this water pollution, exposed groups such as children, adults and elders. Hence, the information used conduct health risk assessment associated with fecal and heavy metal contaminations. The method used for Sampling of questionnaire was random sampling so as to reduce biasness to respondents.

The conducted 389 questionnaires obtained using Solvin formula as shown in equation 1.

Solvin formula of sample size (n)

n=N/(1+Ne^2) …… eqn (1)

Whereby: -

n is sample size

N is population size (14640)

e is margin error (0.005) (Williams, 2024).

Then, the calculated sample size for questionnaire was 389.

Laboratory analysis

Laboratory experiment was conducted so as to determine the pollution level of fecal and heavy metal contaminations at this beach. Parameters measured were pH, turbidity, fecal coliforms especially E. coli and enterococcus and salmonella species and heavy metals such as lead and chromium, Cadmium.

Heavy metals

After sample collection, preservation and transportation, water samples were transported and analyzed at Sokoine University of Agricultural (SUA) by using a method of atomic absorption Spectrometry (AAS). Then, results were provided after one day of analysis.

Fecal coliforms such as E. coli and enterococcus and salmonella species

After sample collection, seven sample collected were analyzed in the laboratory. Starting with analyzing the presence of variety bacteria nutrient agar were used.

- **Steps used in analyzing the presence of variety bacteria using nutrient agar**

Seven petri dishes with nutrient agar were prepared. 0.1 ml of each sample was placed in each plate containing nutrient agar by using micropipette. All plates with samples were placed into an incubator at 37°C for 24 hours (Haugland, Oshima, & Varma, 2021).

- **Steps used in analyzing the presence of E. Coli using MacConkey agar**

MacConkey agar powder marked 51.5 grams in a liter distilled water, glass bottle, hot plate, stirring rod, autoclave and sterile petri dishes were used in preparation of MacConkey agar. MacConkey Agar Powder was weighted Powder was dissolved

transferred to clean flask and distilled water was added, powder and distilled water were mixed and stirred. The mixture was sterilized by autoclave at a 121°C for 15 minutes. After autoclaving, the flask was removed from autoclave and allowed to cool at room temperature. The agar was still liquid, the cooled sterile MacConkey agar was poured into sterile petri dishes. Dishes filled to a depth of approximately 3-4 mm and allowed to solidify. 0.1 ml of original sample was transferred onto center of the agar plate. By using sterile bent glass rod liquid was spread evenly over the entire surface of the agar**, pe**tri dishes were placed into incubator at a 37°C for 24 hours (Ryan, 2014).

- **Steps used in analyzing the presence of enterococcus using KF streptococcus agar**

KF streptococcus agar powder was weighted, glass bottle, hot plate, stirring rod, autoclave and sterile petri dishes were used in preparation of KF streptococcus agar. Powder was dissolved and transferred to clean flask and distilled water was added, powder and distilled water were mixed and stirred. The mixture was sterilized by autoclave at a 121°C for 15 minutes. After autoclaving, the flask was removed from autoclave and allowed to cool at room temperature. The agar was still liquid, the cooled sterile KF streptococcus agar was poured into sterile petri dishes. Dishes filled to a depth of approximately 3-4 mm and allowed to solidify. 0.1 ml of original sample was transferred onto center of the agar plate. By using sterile bent glass rod liquid was spread evenly over the entire surface of the agar**, pe**tri dishes were placed into incubator at a 37°C for 24 hours (Ryan, 2014).

- **Steps used in analyzing the presence of salmonella typhi using Bismuth sulphite agar**

Bismuth sulphite agar powder was weighted, glass bottle, hot plate, stirring rod and sterile petri dishes were used in preparation of Bismuth sulphite agar. Powder was dissolved and transferred to clean flask and distilled water was added, powder and distilled water were mixed and stirred. The mixture was sterilized by hot plate at a 100°C for 15 minutes. After boiling, the flask was removed from hot plate and allowed to cool at room temperature. The agar was still liquid, the cooled sterile Bismuth sulphite agar was poured into sterile petri dishes. Dishes filled to a depth of approximately 3-4 mm and allowed to solidify. 0.1 ml of original sample was transferred onto center of the agar plate. By using sterile bent glass rod liquid was spread evenly over the entire surface of the agar**, pe**tri dishes were placed into incubator at a 37°C for 2 days (Ryan, 2014).

Data analysis Tool

Data analysis from the results obtained were performed by using different tools including SPSS and software named Microsoft excel. Human health risk assessment associated with fecal and heavy metal contaminations

Microbial risk assessment methods

During the health risk assessment associated with fecal contamination, in dose response analysis step, Beta Poisson model was used to determine the probability of infections as shown in equation (2, and 4) (Teunis & Havelaar, 2000).

$P = 1 - (1 - N/\beta)\ \alpha$ ……. eqn (2)

Whereby: - P = Probability of infection from a single exposure

N = Number of organisms ingested per exposure

α and β = Model parameter characterizing the host parasite interaction (Haas, Rose, & Gerba, 1993).

Some values for α and β for several enteric waterborne pathogens are as follows:

Enterococcus the best model is exponential and the model parameter k = 1 x 10^-7 (lower infectivity) as shown in equation (3) (Xiwei & Huang, 2020).

Escherichia coliform – the best model is beta poison and the model parameter α = 0.1705 and β = 1.61 x 10^6 (Haas, Rose, & Gerba, 1993).

$P = 1 - \exp(-k\ N)$ ……. eqn (3)

Where: k = Fraction of the ingested microorganisms that survive to initiate infections.

P = 1- {1 + d/N50(2^ (1/ α) -1)} ^- α ……. eqn (4)

Whereby: -

d is dose or number of pathogens

α is parameter of beta distribution

N50 is the dose that causes half of the exposed population (Teunis & Havelaar, 2000).

Health risk assessment methods for heavy metals contamination

Carcinogenic risk

Carcinogenic risk was calculated by using different formulas as shown in equation (5 and 6).

Incremental lifetime cancer risk (ILCR) = DAD * CSF……. eqn (5)

Where by DAD is Dermal absorbed dose

CSF is Cancer slope factors

DAD = Cw*SA* Kp* ET*EF*ED/ BW*AT……. eqn (6)

Where by: -

DAD dermal absorbed dose in (mg/kg-day)

Cw is concentration of heavy metal in water (mg/cm3)

EF is exposure frequency (days per year)

ED is exposure duration (years)

BW is the average body weight (kg)

AT is Average time (days)

SA is exposed skin area (cm2)

ET is exposure time (h/day)

Kp is dermal permeability coefficient (cm/h) of heavy metal in water (Kim & Jeong, 2012).

Non carcinogenic risk

Potential toxicity for non-carcinogenic was calculated by using different formulas as shown in equation (7 and 8).

Hazard quotient HQ = DAD/RFD……. eqn (7)

Where by DAD is Dermal absorbed dose

RFD is dermal reference dose

Hazard index =$\sum nk$=1 DAD / RfDdermal or $\sum nk$=1 HQ……. eqn (8)

HI>1 high risk for non-carcinogenic (Moradinia, 2024).

Dermal reference dose and cancer slope factor for each metal are found in US EPA (Crawford et al., 2004). Data required for heavy metal health risk assessment such as Concentration of heavy metals exposure duration, frequency, average body weight, average time, exposure skin area, exposure time and dermal permeability coefficient are shown in Table 3.2.

Risk criteria

- Exposure route through Dermal contact due to swimming
- Exposure route through oral ingestion
- Probability of illness based on maximum and minimum countable concentration of each pathogen.

FINDINGS

Introduction

This chapter presented and discussed results according to three core specific objectives such as identification of pollution sources and level of coastal water pollution, establishment of human health assessment associated with fecal and heavy metal contaminations and establishment of mitigation measures to reduce identified human health risk for fecal and heavy metal contaminations. The chapter discussed results by presenting results, cause and implications of the results.

Identification of sources and level of coastal water pollution emphasis on fecal and heavy metal contaminations

Identification of sources of coastal water pollution

Open defecation

It was observed that feces were present at this beach, which implies that people do open defecation. Areas

Urban runoff

It was observed that there is runoff from different areas at Msasani that introduce pollutants into this beach. Results of water sample A1 (urban runoff) and sample A7 (urban runoff) revealed to have enterococcus, E. Coli and Salmonella typh. This indicates that the runoff entered this beach had contaminated with fecal matter. Runoff carries fecal matters because different household in unplanned settlements open their toilets during rainfall so storm water can carry fecal matter. This leads to fecal contamination that expose swimmers and other people to pathogens, hence threatening the public health since fecal matter carry pathogens when swallowed or ingested and contact exposed may lead to skin rashes, diarrhea, vomiting and typhoid fever.

Also, results revealed that urban runoff from sample A8 and sample A10 contributed to heavy metal contamination in this beach as shown in Table 4.1. This is due to presence of heavy metals from industrial wastes, garages and vehicle wastes in the city of Dar es salaam carried by rainfall water to this beach. High concentration of heavy metals, may pose significant carcinogenic and non-carcinogenic effects such as neurological and kidney damage, when swimmers swallow and dermal contact with this contaminated water while swimming.

Sewage discharge

It was found that there are two sewage outlets that discharge sewage into this beach. This sewage comes from Msasani residences. During rainfall this sewage is mixed with storm water. So, they contaminate this beach with fecal matters and heavy metals. People at Msasani use sewage system as a sanitation practice to handle their human waste, but poor management in treating this sewage cause fecal and heavy metal contamination in this beach. This means that swimmers and other people are at risk of being exposed to pathogens related to fecal matter as well as heavy metal contamination. This mean there is significant carcinogenic and non-carcinogenic effects such as neurological and kidney damage and water related diseases including cholera and typhoid when swimmers swallow and dermal contact with this contaminated water while swimming.

Swimming activities

It was observed that people swim in this beach although it contains fecal matter from sewage discharge, runoff and open defecation. Fisher defecates in this beach but also swimmers defecate while swimming because they are not aware of the consequences of defecation in water. Defecation during swimming implies that the beach is contaminated with fecal matter led to threated public health by causing water related diseases including skin rashes, diarrhea, cholera and typhoid when swimmers swallow and dermal contact with this contaminated water while swimming.

Identification of coastal water pollution levels of heavy metals and fecal contamination

Coastal water pollution levels of fecal contamination

Bacteria identified due to fecal contamination were E. Coli, enterococcus, salmonella typh and Salmonella typh. Other parameters measured were pH and Turbidity as shown in Table 4.1.

Table 4. 1:pH and Turbidity and heavy metal results

Samples	pH measured	pH Standards	Turbidity (FAU)	Turbidity standards (FAU)
Sample A1	7.92	7.9 to 8.2	517	2 to 6
Sample A2	7.54	7.9 to 8.2	927	2 to 6
Sample A3	8.25	7.9 to 8.2	1151	2 to 6
Sample A4	8.24	7.9 to 8.2	626	2 to 6
Sample A5	8.21	7.9 to 8.2	464	2 to 6
Sample A6	8.11	7.9 to 8.2	919	2 to 6
Sample A7	8.06	7.9 to 8.2	848	2 to 6
Sample A8	8.21	7.9 to 8.2	634	2 to 6
Sample A9	8.12	7.9 to 8.2	517	2 to 6
Sample A10	7.95	7.9 to 8.2	626	2 to 6
Sample A11	8.23	7.9 to 8.2	464	2 to 6

All water samples had pH above 7.0 which means that they were base. This might be caused by presence of wastes from sewage, feces and urban runoff that changed the pH of water. pH above 7.0 means that water is polluted. All samples had turbidity above standard. This is caused by presence of suspended particles in water. High turbidity also implies that water is polluted but also bacteria are provided with good environment or habitat to live long in this coastal water.

Heavy metal identified were Lead, Chromium and Cadmium. All heavy metal concentrations measured were above standards as shown in Table 4.2. This is due to presence of high potential source of heavy metal at this beach which is urban runoff and sewage discharge. This means that swimmers at this beach maybe exposed to high risk of carcinogenic and non-carcinogenic effects such as reproduction disorders, neurological and kidney damage when

swimmers swallow and dermal contact with this heavy metal contaminated water.

Table 4. 2: Heavy metals identified

Heavy metals identified	Sample A8	Sample A9	Sample A10	Sample A11	TBS standards of natural portable water
Lead (Pb), mg/l	0.521	0.556	0.313	0.414	0.010
Chromium (Cr), mg/l	0.463	0.368	0.405	0.498	0.050
Cadmium (Cd), mg/l	0.388	0.607	0.310	0.320	0.003

Presence of variety bacteria

All bacteria were allowed to grow in nutrient agar, all samples had bacteria that were too numerous to count as shown in Table 4.3. This is due to presence of high potential source of bacteria such as defecation, urban runoff and sewage discharge. This means that the large area of this beach was contaminated with fecal matter. Then these samples were later analyzed in different selective media to identify specific bacteria that were present in each sample.

Table 4. 3: Results of all sample in nutrient agar formed white colonies indicating the presence of variety bacteria

Sample names	Number of bacteria (Colony forming unit per 0.1m)
Sample A1	Too numerous to count
Sample A2	Too numerous to count
Sample A3	Too numerous to count
Sample A4	Too numerous to count
Sample A5	Too numerous to count
Sample A6	Too numerous to count
Sample A7	Too numerous to count

Presence of enterococcus

Starting with identification of enterococcus, KF fecal streptococcus base media was used to culture bacteria from all sample. KF fecal streptococcus base is a selective media that used to identify the presence of enterococcus in each sample. Yellow colonies were formed indicating the presence of enterococcus. Sample A1 (urban runoff) and A7 (urban runoff) had yellow colonies that were too numerous to count means having high concentration of bacteria than other samples. This might be caused by presence of fecal matter in infrastructure that introduces runoff in this beach. Another reason is that people open they toilets during rainfall season at Msasani. Sample that has few colonies for enterococcus was sample A4 (swimming zone), this sample represents water from swimming zone at the middle of this beach. Few counts of enterococcus in this sample A4 compared to other is due to high distance from fecal sources of pollution such as defecation zone and runoff and sewage discharge facility. This means that people are still exposed to enterococcus and the public health is at risk and maybe affected by getting urinary tract infections, head ache and skin diseases. Results of all sample in KF fecal streptococcus agar base formed yellow colonies indicating the presence of enterococcus were shown in Table 4.

Table 4. 4: Results of all sample in KF fecal streptococcus agar base formed yellow colonies indicating the presence of enterococcus

Sample names	Number of bacteria (CFU per 0.1ml)	Number of bacteria (CFU per 100ml)
Sample A1	TNTC (>250)	TNTC
Sample A2	115	115,000
Sample A3	126	126,000
Sample A4	1	1,000
Sample A5	70	70,000
Sample A6	80	80,000
Sample A7	TNTC (>250)	TNTC

Presence of E. Coli

MacConkey agar was used to identify the presence of E. Coli. All samples had E. Coli, bacteria grew on this media with pink to red colonies indicating the presence of E. Coli as shown in Table 4.5. Sample A2 (near defecation zones), A3 (swimming zone), A4 (swimming zone), A6 (near defecation zone) and A7 (urban runoff) had bacteria that were too numerous to count. This is due to presence of high fecal matter in those water sample as main source were defecation and runoff. While sample A5 (swimming zone) had 13,000 pinks to red colonies in 100 ml. Generally, due to these results water is contaminated by fecal matter, hence swimmers and

other people are at significant health risk by being exposed to E. Coli which might cause vomiting, diarrhea head ache, urinary tract infections and other gastrointestinal effects.

Table 4. 5: Results of all sample in MacConkey agar formed red to pink colonies indicating the presence of E. Coli

Sample names	Number of bacteria (CFU per 0.1m)	Number of bacteria (CFU per 100 ml)
Sample A1	42	42,000
Sample A2	TNTC (>250)	TNTC
Sample A3	TNTC (>250)	TNTC
Sample A4	TNTC (>250)	TNTC
Sample A5	13	13,000
Sample A6	TNTC (>250)	TNTC
Sample A7	TNTC (>250)	TNTC

Presence of Salmonella typhi

Results of all sample in Bismuth sulphite agar formed black colonies indicating the presence of Salmonella typh after three days of incubation are shown in Table 4.6. all samples had clear colored colonies. Again, sample A7 (urban runoff) had black colonies which were too numerous to count. Indicating the presence of salmonella typh in this sample. The sample A7 is having high salmonella typhi in high number because urban runoff may carry large amount of fecal matter from households that open their toilets during the rainfall season. Sample A5 (swimming zone) had 67,000 black colonies in 100 mls, which is less than the other samples. These pathogens can reach different areas in the beach by being transported by water to different areas. Generally, results had high counts of salmonella typhi means that people are exposed to fecal contamination and have high risk of getting typhoid fever.

Table 4. 6: Results of all sample in Bismuth sulphite agar formed black colonies indicating the presence of Salmonella typh after three days of incubation

Sample names	Number of bacteria (CFU per 0.1m)	Number of bacteria (CFU per 100 ml)
Sample A1	152	152,000
Sample A2	120	120,000
Sample A3	206	206,000
Sample A4	124	124,000
Sample A5	64	64,000
Sample A6	246	246,000
Sample A7	TNTC (>250)	TNTC

Finally, FC/FS calculated was 3.27 this means that human source is a predominantly source of fecal contamination at this beach. This is due to presence of defecation, sewage discharge and urban runoff which may carry fecal matter during rainfall to this when people open their toilets.

Establishment of health risk assessment based on the concentration level of heavy metals such and fecal contamination

Microbial risk assessment associated with fecal contamination

Hazard Identification

Identified bacteria were E. Coli, enterococcus and salmonella typh as shown in Table 4.7. Sources of these bacteria identified were defecation, sewage discharge, storm water runoff and swimming activities as explained in objective number one.

Table 4. 7: Overall bacteria identified in all water samples

Sample names	E. coli (Colony forming unit per 100ml)	Enterococcus (Colony forming unit per 100ml)	Salmonella typh (Colony forming unit per 100ml)
Sample A1	42,000	TNTC	152,000
Sample A2	TNTC	115,000	120,000
Sample A3	TNTC	126,000	206,000
Sample A4	TNTC	1,000	124,000
Sample A5	13,000	70,000	67,000
Sample A6	TNTC	80,000	246,000
Sample A7	TNTC	TNTC	TNTC

Exposure assessment

People came into contact with pathogens through dermal contact and oral ingestion when swimming. Swimming activities provides chances of people to swallow water and be contaminated by getting into contact with fecal contaminated water. People swim

because of reaction factors. This means that people are exposed to identified bacteria.

Oral exposure, about 90% of respondents, swimmers swallow water during swimming. 50% respondent accepted to drink a lot, according to US EPA (2019), water ingestion rate while swimming or diving is 96 ml/hour for ages 6 to <11 and 152 ml/ hour for 11+ ages. In addition, 71% of respondents the exposure time is 2 hours in a day, this means that most swimmers they expose themselves for a long time in a day for about 2 hours and hence swallow a significant amount of water. This proves that swimmers drink this contaminated water during their swimming making then exposed through oral ingestion.

Dose-Response Assessment

During the dose response assessment, the probability of infection was calculated using the beta Poisson model for E. Coli, salmonella typhi and enterococcus by using their respective concentrations of counts. Then followed by annual risk, lifetime risk, risk of illness and risk of mortality. In order to obtain range of probabilities and risks, the calculation was done by using maximum and minimum countable concentration of each pathogen.

Starting with dose response assessment for pathogens with their maximum countable concentrations results are shown in Table 4.8. Probability of infection was 0.33157 for salmonella typhi which is larger compared to probabilities of E. Coli and enterococcus. This means that swimmers are at a probability of 33.157% of being infected by salmonella typhi which is high probability.

Annual risk was 1 for salmonella typhi which was high compared to E. Coli and enterococcus. This means that swimmers are at high risk in a year of being infected by Salomon typh than E. Coli and enterococcus. This is due to high concentration of salmonella typhi. Lifetime risk was 1 for all pathogens means that people are at high risk of being infected by all three pathogens during their lifetime of 70 year. Overall, all pathogens have high chance of causing infection to swimmers, all pathogens are having high risk of cause infection in a year and in lifetime of swimmers. This is due to high level of pollution at this beach.

In a case of risk of illness and risk of mortality, the salmonella typhi had 0.165777 and 0.0331554 which was greater than risk of illness and risk of mortality for E. Coli and enterococcus as shown in Table 4.8. But E. Coli and enterococcus their risk of illness and mortality were above 0.0001 US EPA acceptable risk. So, this means that all pathogens had high risk of illness and mortality due to their high counts in water samples. This is also caused by high level of coastal water pollution that is present ta this beach.

Table 4. 8: Dose response assessment results for maximum countable concentrations of pathogens

Pathogenic organisms	Maximum countable concentration CFU per 100 ml	probability of infection	annual risk ($P_A = 1-(1-P)^{365}$)	lifetime risk ($P_L = 1-(1-P)^{25550}$)	risk of illness (PI = P x I)	risk of mortality (PM = PI x M)
Escherichia coli	42,000	0.00044967	0.806 99	1	2.24835x10^-3	4.4967 x10^-4
Salmonella typhi	246,000	0.331547	1	1	0.165 777	0.03315 54
Enterococcus	126000	0.01252	0.9899	1	6.26 x10^-3	1.252 x10^-3

Lastly, dose response assessment was also done by using minimum countable concentrations of pathogens as shown in Table 4.9. The probability of infection was 0.23358 for salmonella typhi which was also a larger probability when compared to E. Coli and enterococcus. Even in lower countable concentrations the concentration of salmonella typhi was larger than to that of E. Coli and enterococcus. So, there is high probability of swimmers to be infected by salmonella typhi.

In annual risk salmonella had 1 high which is greater than that of E. Coli and enterococcus. This means that swimmers are at high risk of being infected by salmonella typhi in a year. But also, there is a risk of 39.63% of being affected by E. Coli. While there is lower risk of being infected by enterococcus. The cause of high annual risk is the presence of large number of bacteria due to presence of high potential fecal pollution sources at this beach. Finally, annual

risk with minimum countable concentrations, the public health is at high risk of being affected by salmonella typhi and E. Coli.

The lifetime risk for Salmonella typhi, E. coli and enterococcus was high. This is due to significant values of their probabilities of infection leading to give high chance of exposed swimmers to be at high risk of being affected during their lifetime of 70 years. This means that if swimmers are exposed to this contaminated water for their lifetime of 70 years, there is high chance for them to be infected by all these pathogens.

Risk of illness with minimum countable concentrations of these pathogens 0.11679 for salmonella typhi which was higher than risk of illness for E. Coli as shown in Table 4.9. and enterococcus. Also, it is the same for risk of mortality. This is due to high probability of infection of salmonella typhi. This means that swimmers are at high risk of getting ill by salmonella typhi and high risk of mortality by being infected by salmonella typhi.

Table 4. 9: Dose response assessment results for maximum countable concentrations of pathogens

Pathogenic organisms	Minimum countable concentration CFU per 100 ml	probability of infection	annual risk ($P_A = 1-(1-P)^{365}$)	lifetime risk ($P_L = 1-(1-P)^{25550}$)	risk of illness (PI = P x I)	risk of mortality (PM = PI x M)
Escherichia coli	13,000	0.001381 3	0.3962	1	6.90655 x10^-4	1.3813 x10^-4
Salmonella typhi	67,000	0.23358	1	1	0.116 79	0.023358
Enterococcus	1000	0.0001	0.03584	0.9223	5 x10^-5	1 x10^-5

Risk characterization

All risks of illness and risks of mortality for all pathogens except for enterococcus with lower concentration were not acceptable. This means that all risks were above 0.0001 US EPA acceptable risk level except for enterococcus with minimum countable concentration as shown in Table 4.10 and 4.11. Means that for identified risks of illness and mortality there is high chance that 1 swimmer can be infected and get ill and die out of 1000 swimmers if the contamination level remains at this level.

- **Human health symptoms**

In this step swimmers/respondents were assessed on symptoms they felt few hours or days after swimming. 57% of respondents had diarrhea and 71% respondents had vomiting. This is due to presence of E coli, salmonella typhi and enterococcus they cause vomiting and diarrhea when ingested. This implies that there is high chance of swimmers to be infected by these pathogens.

55% swimmers had nausea and 76% had stomach cramps. This is due to presence of E coli, salmonella typhi and enterococcus they cause stomach pain and nausea when ingested. This implies that there is high chance of swimmers to be infected by these pathogens.

71% swimmers had fever and 67% had headaches. This is due to presence of E coli, salmonella typhi and enterococcus they cause headaches and fever when ingested. This implies that there is high chance of swimmers to be infected by these pathogens.

62% respondents had urinary tract infections. This is due to presence of E coli, and enterococcus they cause urinary tract infections when reach urinary track system. This implies that there is high chance of swimmers to be infected by these pathogens.

Health risk assessment for heavy metal contamination through dermal contact

- **Hazard identification**

Heavy metal identified were Lead, Chromium and Cadmium. All heavy metal concentrations measured were above TBS standards of natural portable water as shown in Table 4.12. This is due to presence of high potential source of heavy metal at this beach which is urban runoff. This means that swimmers and other people at this beach maybe exposed to high risk of carcinogenic and non-carcinogenic effects such as reproduction disorders, neurological and kidney damage when swimmers swallow and dermal contact with this heavy metal contaminated water

Table 4. 10: Heavy metals identified

Heavy metals identified	Sample A8	Sample A9	Sample A10	Sample A11	TBS standards of natural portable water
Lead (Pb), mg/l	0.521	0.556	0.313	0.414	0.010
Chromium (Cr), mg/l	0.463	0.368	0.405	0.498	0.050
Cadmium (Cd), mg/l	0.388	0.607	0.310	0.320	0.003

- **Exposure assessment**

Dermal contact through swimming activities is potential exposure for swimmers to be infected by this pathogen. 52% respondents had open wounds or cuts while swimming during their visit in this beach. They swim with open wounds because they are not aware of the consequences. Swim with open wounds increase the risk of being affected by these heavy metals through dermal contact.

Exposure frequency and exposure time, 90.5% respondents the frequency of exposure is twice a week. 71% of respondents the exposure time is 2 hours in a day. They had high exposure time because most of them are kids and they use a lot of time having fun for swimming during weekends. This means that most swimmers they expose themselves for a long time in a day for about 2 hours hence increases high chance of being affected by heavy metals.

Most exposed people are children about 90% of respondents aged between 6 and 17 years old this is because children have time and desire to have fun by swimming than adults, adults also do not have much time to spend for swimming and last factor is that adults feel shame to swim at the open beach than children do. This implies that most exposed swimmers are children.

Skin surface area exposure for adult is 18,000 cm^2 and for child is 6,600 cm^2 when swimming (Reiley, 2007). This step involved calculation of dermal absorbed dose. The range of dermal absorbed dose for carcinogenic which was high compared to other identified heavy metal was 1.35E-4 to 9.96E-5 by chromium as shown in Table 4.13 and Table 4.14. Because chromium has high permeability coefficient than cadmium.

For non-carcinogenic, the range of dermal absorbed dose in child which was high compared to other metals identified was 2.3E-4 to 1.7E-4 by chromium as shown in Table 4.13 and Table 4.14. As explained before the chromium has high permeability coefficient than cadmium. In adults it ranges from 1.35E- to 9.96E-5 by chromium. This means that people are at high risk of getting cancer due to chromium contamination than cadmium through dermal contact.

Table 4. 11: Maximum dermal absorbed doses

Heavy metals identified	Maximum concentration (mg/l)	DAD (mg/kg-day) for carcinogenic	DAD (mg/kg-day) for non carcinogenic in Child	DAD (mg/kg-day) for non carcinogenic in Adults
Chromium (Cr)	0.498	1.347231311E-4	2.305262466E-4	1.347231311E-4
Cadmium (Cd)	0.607	8.210536204E-5	1.404913973E-4	8.210536204E-5

Table 4. 12: Minimum dermal absorbed doses

Heavy metals identified	Minimum concentration (mg/l)	DAD (mg/kg-day) for carcinogenic	DAD (mg/kg-day) for non carcinogenic in Child	DAD (mg/kg-day) for non carcinogenic in Adults
Chromium (Cr)	0.368	9.955444227E-5	1.70348712E-4	9.955444227E-5

Cadmium (Cd)	0.310	4.193189824E-5	7.175013699E-5	4.193189824E-5

Carcinogenic, average daily potential dose range from 8.3E-3 to 4.24 by cadmium which was greater than average daily potential dose by lead and chromium. This is because cadmium had 0.607 higher concentration than other metals. So, by oral ingestion cadmium has high dose for carcinogenic.

Non carcinogenic, average daily potential dose ranged from 0.0245 to 0.012 by cadmium higher than chromium and lead in child as shown in Table 4.15 and 4.16. Children are exposed to high dose than adults to due to their small average body weight. This means that children are more exposed to heavy metals than adults.

Table 4. 13: Maximum average daily potential doses

Heavy metals identified	Maximum concentration (mg/l)	ADD (mg/kg-day) for carcinogenic	ADD (mg/kg-day) for non carcinogenic in Child	ADD (mg/kg-day) for non carcinogenic in Adults
Lead (Pb)	0.556	7.620965E-3	0.02246179	7.620965E-3
Chromium (Cr)	0.498	6.825972E-3	0.02011865	6.825719E-3
Cadmium (Cd)	0.607	8.320001E-3	0.02452213	8.320001E-3

Table 4. 14: Minimum average daily potential doses

Heavy metals identified	Minimum concentration (mg/l)	ADD (mg/kg-day) for carcinogenic	ADD (mg/kg-day) for non carcinogenic	ADD (mg/kg-day) for non carcinogenic in Child	Adults
Lead (Pb)	0.313	4.290219335E-3	0.012644856	4.290219335E-3	
Chromium (Cr)	0.368	5.044091 7E-3	0.014866796	5.044091 7E-3	
Cadmium (Cd)	0.310	4.249099E-3	0.01252366	4.249090E-3	

- **Toxicity assessment**

At site, the dermal contact may result in direct toxicity or systematic toxicity. This step involved the calculation of absorbed toxicity values. It involved calculation of cancer slope factor based of absorbed dose (SF*abs*) and reference dose RfD*abs.*

Cancer slope factor absorbed (SFabs)=SFo/ABS*GI*

Whereby: -

ABS*GI* is fraction of contaminants absorbed in gastrointestinal track. ABS*GI* for chromium is 2.5% and for cadmium is 5% (Reiley, 2007).

Oral cancer slope factors (per mg/kg-day) used were 0.0085 for lead, 0.5 for chromium and 0.38 for cadmium. Then, calculated cancer slope factors absorbed (per mg/kg-day) are 20 for chromium and 7.6 cadmium.

Reference dose absorbed (RfDabs)=RfDo*ABS*GI*

Oral reference dose (mg/kg-day) used were 0.0035 for lead, 0.003 for chromium and 0.001 for cadmium (Reiley, 2007). Then, calculated reference dose absorbed (mg/kg-day) are 7.5E-5 for chromium and 5E-5 for cadmium. Reference dose absorbed were small than oral reference dose because of the fraction of contaminants absorbed.

- **Risk characterization**

This step involves risk calculation. Cancer risk and hazard index for the dermal route are calculated. Cancer risk is calculated by using dermal absorbed dose and absorbed cancer slope factor While hazard index is calculated by using dermal absorbed dose and absorbed reference dose (Kim & Jeong, 2012).

For non-carcinogenic risk, dermal hazard quotients in children were high for chromium ranged from 3.07 to 2.27 than cadmium. Children are having high dermal hazard quotient than adults as shown in Table 4.17 and Table 4.18. This is due to small body weight of children exposed to same concentration of heavy metals to adults (having high body weight).

The overall hazard quotients were all above 1 means that there is high potential for non-carcinogenic effects to occur.

Table 4. 15: Maximum derma hazard quotients

Heavy metals identified	Maximum concentration (mg/l)	Dermal hazard quotient (DHQ) in child	Dermal hazard quotient (DHQ) in adult
Chromium (Cr)	0.498	3.07368	1.7963
Cadmium (Cd)	0.607	2.8098	1.6421

Table 4. 16: Minimum dermal hazard quotients

Heavy metals identified	Minimum concentration (mg/l)	Dermal hazard quotient (DHQ) in Child	Dermal hazard quotient (DHQ) in adults
Chromium (Cr)	0.368	2.271	1.327
Cadmium (Cd)	0.310	1.435	0.839

Target hazard quotient for oral ingestion was high in cadmium ranged from 24 to 12.5 in children. All other target hazard quotients were above 1 means high potential to cause non carcinogenic effects as shown in Table 4.19 and Table 4.20. Children had target hazard quotients high than adults. But all in all, there is high potential risk of non-carcinogenic effects to swimmers.

Overall, Target hazard quotients were high than dermal hazard quotients for both children and adults, because oral ingestion of these heavy metals have high effects that dermal contact with water. This means that swimmers swallowing water while swimming are at high risk of getting non carcinogenic effects.

Table 4. 17: Maximum target hazard quotients

Heavy metals identified	Maximum concentration (mg/l)	Target hazard quotient (THQ) in child	Target hazard quotient (THQ) in adult
Lead (Pb)	0.556	6.418	2.177
Chromium (Cr)	0.498	6.706	2.275
Cadmium (Cd)	0.607	24.522	8.320

Table 4. 18: Minimum target hazard quotients

Heavy metals identified	Minimum concentration (mg/l)	Target hazard quotient (THQ) in child	Target hazard quotient (THQ) in adult
Lead (Pb)	0.313	3.613	1.226
Chromium (Cr)	0.368	4.955	1.668
Cadmium (Cd)	0.310	12.524	4.249

Dermal contact carcinogenic risk, all carcinogenic risk were above 0.0001 US EPA acceptable risk level as shown in Table 4.21 and Table 4.22. Through dermal contact the range of risk from 2.69E-3 to 1.99E-3 by chromium. This is due to high permeability coefficient of chromium which is higher than cadmium. Generally, swimmers are at a significant risk of getting cancer through dermal exposure.

Table 4. 19: Maximum lifetime cancer risk for dermal contact by

Heavy metals identified	Maximum concentration (mg/l)	Lifetime cancer risk (ILCR) for Dermal contact	US EPA ACCEPTABLE RISK	Remarks
Chromium (Cr)	0.498	2.6945 E-3	10-4 to 10^-6	Not acceptable
Cadmium (Cd)	0.607	6.240003E-4	10^-4 to 10^-6	Not acceptable

Table 4. 20: Minimum lifetime cancer risk for dermal contact

Heavy metals identified	Minimum concentration (mg/l)	Lifetime cancer risk (ILCR) for Dermal contact	US EPA ACCEPTABLE RISK	Remarks
Chromium (Cr)	0.368	1.99108E-3	10^-4 to 10^-6	Not acceptable
Cadmium (Cd)	0.310	3.186823E-4	10^-4 to 10^-6	Not acceptable

Oral ingestion carcinogenic risk, all carcinogenic risks were above 0.0001 US EPA acceptable risk level except for lead as shown in Table 4.23 and Table 4.24. High risk level ranged from 3.4E-3 to 2.52E-3 by chromium which was high range than from other heavy metals. Lead had acceptable risk level of cancer ranged from 6.48E-5 to 3.65E-5. Chromium had high carcinogenic risk than others because it has high oral cancer slope factor and average daily potential dose. This means that swimmers are at high risk of getting cancer through oral ingestion of chromium than cadmium and lead. Overall, carcinogenic risk through oral ingestion is high than carcinogenic risk through dermal contact. So, swimmers swallowing water while swimming is at high risk of getting cancer.

Table 4. 21: Maximum lifetime cancer risk for oral ingestion

Heavy metals identified	Maximum concentration (mg/l)	Lifetime cancer risk (ILCR) for oral ingestion	US EPA ACCEPTABLE RISK	Remarks
Lead (Pb)	0.556	6.477816E-5	10^-4 to 10^-6	Acceptable
Chromium (Cr)	0.498	3.412986E-3	10^-4 to 10^-6	Not acceptable
Cadmium (Cd)	0.607	3.1616038E-3	10^-4 to 10^-6	Not acceptable

Table 4. 22: Minimum lifetime cancer risk for oral ingestion

Heavy metals identified	Minimum concentration (mg/l)	Lifetime cancer risk (ILCR) for oral ingestion	US EPA ACCEPTABLE RISK	Remarks
Lead (Pb)	0.313	3.646686 4E-5	10^-4 to 10^-6	Acceptable
Chromium (Cr)	0.368	2.52204585E-3	10^-4 to 10^-6	Not acceptable
Cadmium (Cd)	0.310	1.61465762E-3	10^-4 to 10^-6	Not acceptable

Mitigation measures to reduce identified human health risks for fecal and heavy metal contaminations

Mitigation measures for fecal contamination

- **Introduction of public toilets with proper sanitation facilities**

Public toilets will prevent open defecation at this beach. Public toilets with proper sanitation facilities will help to handle human waste from people living at this beach without proper homes especially fishers. When defecation is prevented, the fecal contamination level will also decrease.

- **Proper sewage treatment before discharge to coastal water**

Sewage water has to be properly treated before discharged into the ocean. When sewage is treated well, bacteria and other microorganisms are killed. So, this will reduce fecal contamination in this beach and make this coastal water safe for swimming.

- **Enforcement of regulations on sewage discharge Strictly punishment to households who open their toilets during rainfall seasons**

Households who open their toilets during rainfall season they have to be identified and strictly punished. This will reduce fecal matter that may enter the coastal water through runoff, hence reduce the risk of pathogens to cause infection to swimmers.

- **Enforcement of regulations on open defecation**

People who defecation at this beach has to be strictly punished. Environmental Management Act of 2004, has to be enforced. This will prevent defecation at this beach and hence help to reduce fecal contamination.

- **Awareness provision and community engagement**

People living near this beach especially fishers who have no proper homes and toilets have to be aware of the consequences of defecate at this beach. They have to be given awareness to find toilets with proper sanitation facilities.

4.4.2 Mitigation measures for heavy metal contamination

- **Source control by using constructed wetland**

Constructed wetlands can be used to treat urban runoff water before reaching the coastal water. Constructed wetlands can help to reduce heavy metal contamination of urban runoff before reaching the coastal water. By doing so, it will reduce concentration of heavy metals reaching this beach and hence reduce risk of carcinogenic and non-carcinogenic effects.

- **Remediation of contaminated coastal water and sediments by using phytoremediation**

Mangroves when planted in aquatic area contaminated with heavy metals they tend to accumulate them in roots, so by using mangroves heavy metals can be remediated at this beach. The beach has areas available for phytoremediation by using mangroves. It is ecological friendly and it doesn't change the environment of the beach in negative way. Also using mangroves to remediate this beach is cost effective. This method can help to reduce the present concentration of heavy metals in coast water and its sediments hence reduce risks for carcinogenic and non-carcinogenic effects to occur.

- **Strict enforcement of industrial discharges regulations**

There is a lot of industries in Dar es salaam of which their chemical wastes may contain heavy metals, so during the rainfall these heavy metals are carried by urban runoff and reach coastal water. Environment regulation of 2007 that guides industrial discharges has to be strongly enforced to make sure that industrial discharges waste which are within standards. This will reduce heavy metal contamination in coastal water.

- **Proper sewage treatment before discharge to coastal water**

Sewage may contain heavy metals, so when treated well heavy metals can be reduced to concentrations that are low enough to pose less significant impact to human health. So, treating properly this sewage will reduce heavy metal contamination and hence reduce risks for carcinogenic and non-carcinogenic effects.

CONCLUSION AND RECOMMENDATION

Conclusion

Fecal pollution sources identified were open defecation, sewage discharge and storm water runoff. Since the FC/FS ratio was 3.27 the human source is a predominantly source of fecal contamination. Heavy metal pollution source was urban runoff. E. coli was found to be at high level compared to salmonella typhi and enterococcus. All heavy metal identified were above TBS Standards limits for natural portable water.

All microbial risks of illness identified from each pathogen with their respective concentrations were above 0.0001 US EPA acceptable risk except for enterococcus with lower concentration. All hazard quotients for all metals were above 1 (high) except for Cd with minimum concentration in adult through dermal contact and all carcinogenic risks were not acceptable except for Pb.

Basically, enforcement of sewage discharge and introduction of public toilet with proper sanitation facilities and strict punishment to households who open their toilets during rainfall seasons can reduce identified risks. Phytoremediation and constructed wetland can reduce heavy metal identified human health risks.

Recommendation

Source control such as constructed wetland and phytoremediation at the site can reduce heavy metal pollution. Environmental Management (Water Quality Standards) Regulation 2007, states that distance to source of contamination should be minimum 100 meter, has to be enforced.

Since most microbial risks identified were above 0.0001 US EPA acceptable level and non-carcinogenic and carcinogenic risks were high and not acceptable, people should temporarily stop swimming until risk levels are reduced.

Phytoremediation and constructed wetland can reduce heavy metal identified risks but further investigation is recommended. Introduction of

public toilet with proper sanitation facilities and enforcement of Environmental Management Act, 2004 can reduce microbial risks identified.

References

Boulainine, D. (2024). Spatial Temporal dynamics of bacteria communities in Algeian watershed impacted by fecal pollution. *water*, 1123.

Buitrago, N. (2024). Understanding the animal waste issue on world beaches. *Ocean and coastal management*, 107287.

Chibuke, A. (2022). Microbiology techniques and methds: basic techniques and microscopy. *Analytical Techniques* , 201-220.

Chibuke, A. (2022). Microbiology techniques and methds: basic techniques and microscopy. *Analytical Techniques* , 201-220.

Colombo, V. (2023). Environmental determinants of access to share sanitation in informal settlements . *infection diseases*, 12.

El-Sharkawy, M. (2025). Heavy metal pollution in coastal environments. *Sustainability*, 701.

Genco, R. (2020). Clinical and public health implications of periodontal and systemic diseases. *periodontology*.

Gleick, P. (2020). Dirty water estimated deaths from water related diseases . *Pacific institute for studies in development, environment and security*.

Gunasekara, I. (2025). Pollution from land based sources: industrial and urban runoff. *coastal and marine pollution*.

Haas, C., Rose, J., & Gerba, C. (1993). Risk assessment of virus in drinking water. *Risk analysis*, 13.

Haugland, R., Oshima, K., & Varma, M. (2021). Large scale comparison of E. coli levels determined by culture . *microbiology methods*, 106186.

Haugland, R., Oshima, K., & Varma, M. (2021). Large scale comparison of E. coli levels determined by culture . *microbiology methods*, 106186.

Jade, M., & Weir, M. (2025). Salmonella typhi: dose response experiments. *Michigan state university*, -.

Kim, J., & Jeong, J. (2012). Heavy metal risk management. *Toxicology research*, 143-149.

Mallin, M. (2010). Bacteria source tracking guides management of boat head waste in coastal water. *Environmental management*.

Manetu, W. (2021). Waterborne diseas risk factors and intervention practices. *open access library* .

Moradinia, M. (2024). Assessing the carcinogenic and non-carcinogenic health risks of metal in drinking water. *scientific reports*, 14.

Mohammed, S. (2002). A review of water quality and pollution studies in Tanzania . *human environment*.

Pangestuti, D. (2020). Feacal contamination in groundwater and its association with population density. *Web conference*.

Paruch, L. (2022). Overview of microbial source using host specific genetic markers to identify original fecal contaminatio. *water*, 11.

Pommepuy, M. (2005). Fecal contamination in coastal areas. *Ocean and health*, 331-359.

Powers, N. (2021). Sources, drivers and impacts of fecal c ontaination in Texas. *Texas A&M University*, -.

Reiley, M. (2007). Science, policy and trends of metals risk assessment at EPA. *Aquqtic toxicology*, 292.

Remeteiova, D., & Silvia, R. (2020). Evaluation of US EPA method 3052 microwave acid digestion for quantification of majority metal . *Metals* , 10.

Ryan, M. (2014). Application of quantitative microbial risk assessment for selection of microbial reduction targets for hard surface disinfectants. *Journal of infection control*, 1165.

Shete, A., & Dube, S. (2020). Sample size calculation in bio statistics with special reference to unkown population. *international journal for innovative research in multdisciplinary field*, -.

Silva, F., & Gouveia, R. (2020). Cleaner prodution. *Springer international publishing*, -.

Soller, J. (2016). Use of quantitative microbial risk assessment to improve interpretation of recreational water epidemiology study. *Microbial risk analysis*, 11.

Soulmastre, M., Piccini, J., & Gallego, L. (2022). Spatial and temporal dynamics pathogenicity of fecal coliforms in coastal shallow groundwater wells. *Environmental monitoring and assessment*, 89.

Teunis, P., & Havelaar, A. (2000). The Beta Poisson dose response model is not a single hit model. *risk analysis*, 513-520.

US EPA. (2005). Guidelines for carcinogenic risk assessment. *Risk assessment from U.S Environmental protection agency*.

Wang, L. (2021). Revie of green remediation strategies for heavy metal contaminated sites. *Soil use and management*, 936.

Xiwei, H., & Huang, K. (2020). Assessment technologies for hazards or risks of wastewater. *High risk pollutants in wastewater*, -.

Zan, R. (2023). Innovative stormwater management. *Newcastle univercity*, -.